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Procedia Engineering 123 (2015) 308 – 315
Procedia Engineering
www.elsevier.com/locate/procedia

Creative Construction Conference 2015 (CCC2015)

Application of Relationship Diagramming Method (RDM) for resource-constrained scheduling of linear construction projects

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Abstract

The traditional techniques for project scheduling such as Arrow Diagramming Method (ADM) and Precedence Diagramming Method (PDM) are continuously undergoing improvisation in order to replicate real-time construction scenario. Quite often, these methods are criticized for their limited information capturing ability. Relationship Diagramming Method (RDM) proposed by Plotnick in the recent past, is an improved variant of PDM, which can store additional information on relationships that would improve the scheduling process. In addition to basic data on the activities, additional information can be represented through five codes in RDM. Sequencing of activities in a construction project is primarily driven by the construction logic and/or the availability of resources. There is scope for arriving at alternate sequences with varying availability of resources to achieve the objectives of project scheduling as long as the construction logic is preserved. In order to achieve such a resource-constrained project scheduling, additional information on the restraints of the activities are necessary, which can be modelled using RDM through one of the five codes of RDM. The objective of this paper is to explore and exploit the Reason/Why code of RDM. The Reason and Why codes are associated with a restraint and for recording the description respectively. An activity's dependence on a resource has been captured using Reason/Why code in this study. It has been attempted to understand the impact of varying resource availability using an empirical equation on sequencing such resource dependent activities and its effect on critical path. The proposed concept is tested with data from a repetitive high rise construction project. The preliminary results have been well received.

Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2015

Keywords: critical path; reason/why code; relationship diagramming method; repetitive construction projects; resource-constrained project scheduling

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Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2015
doi:10.1016/j.proeng.2015.10.095

1. Introduction

Execution sequence of activities involved in a construction project is primarily driven by the construction logic and/or the availability of resources such as manpower, equipment, material [1-3]. The sequence of activities, which are logic dependent cannot be altered but the sequence of resource dependent activities can be altered primarily based on the availability of resources at any instance using any of the resource constrained project scheduling methods [4-12]. The traditional scheduling techniques such as ADM (Arrow Diagramming Method) and PDM (Precedence Diagramming Method) cannot distinguish this variations and both the constraints are generally applied together [13-16].

RDM (Relationship Diagramming Method) is a variant of PDM and it can store more information compared to other traditional methods [17]. Fig. 1 shows the comparison of PDM and RDM [18]. In addition to basic data on the activities, additional information can be represented through five codes namely, Event Codes, Reason/Why Codes, Expanded Restraint or Lead/ Lag Codes, Duration Codes and Relationship Codes. The reason/why code of RDM can be associated with a restraint. Primary choices for reason/why code are either “P” for “physical” or “R” for “resource” as presented in Fig. 1. Generally, a physical reason indicates that activity is dependent based on logic and the FS (Finish-to-Start) relationship cannot be violated, whereas the resource reason states that activity are dependent on resource and the FS relationship depends on the resource availability at site [18]. The Why code further describes the Reason code and answers the question of “why” the specific Reason has been chosen. But, the critical path computations based on varying resource availability has not been adequately investigated [19].

Planning for appropriate resources especially the labor has always been a great challenge for project managers. The main objective of this paper is to execute ‘what-if’ scenarios for several resource combinations using the RDM reason/why code on repetitive construction projects. Sharing common resources is the most predominant challenge in repetitive construction projects. Through pattern analysis on several test cases and trial and error methodology, an empirical equation for computing the EF (early finish) of an activity has been determined [19]. Other calculations for network analysis such as ES (early start), LS (late start) and LF (late finish) have been performed in the same way as of ADM. This proposed network analysis was applied on a construction data and the initial findings has been reported.

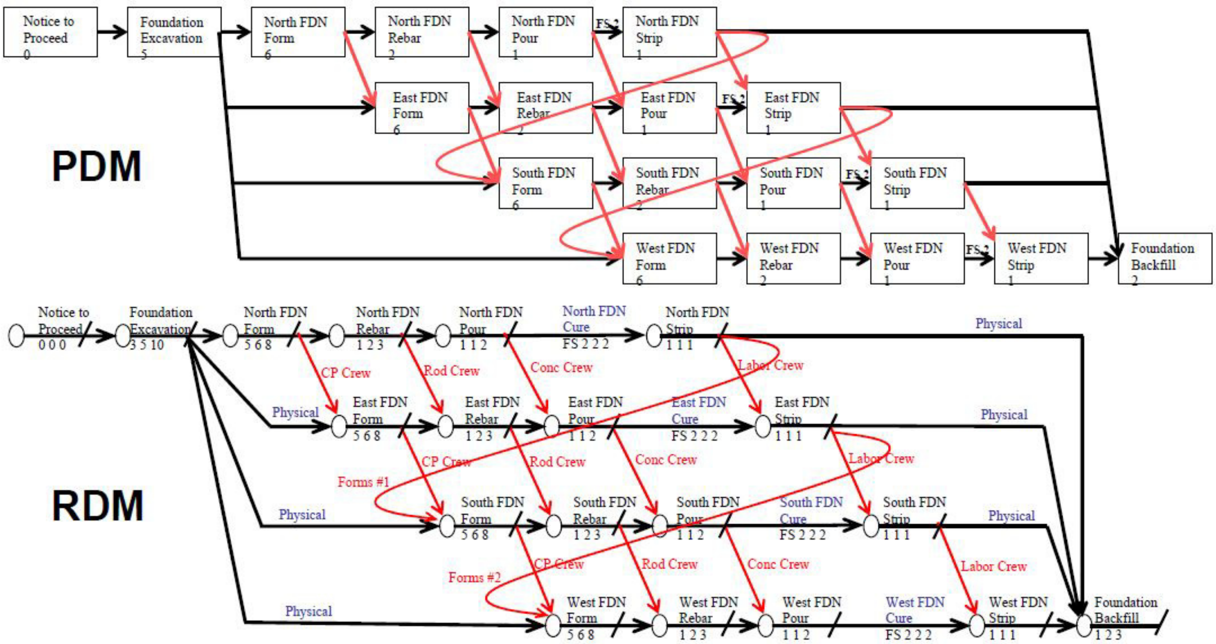

Fig. 1. Comparison of PDM and RDM network representation *(source: [18])*

2. Solution methodology

The proposed solution methodology is presented in Fig. 2 for determining the critical path for RDM networks when what-if analysis is performed on activities that share the common resources. If the available resources are more than the planned number of resources, then the resource dependent activities can be performed simultaneously but their duration depends on the number and combination in which the resources are allocated to them. Hence, the critical path will change for the planned combination of resources according to the arrived duration of each activity. Pattern analysis on several test cases has been conducted with varying resource combinations and a generic empirical equation for forward and backward pass has been arrived at. Except EF, the other calculations performed during the forward and backward pass will not vary and the equation is elaborated subsequently. The equation for calculating the EF for any activity is shown in equation (1).

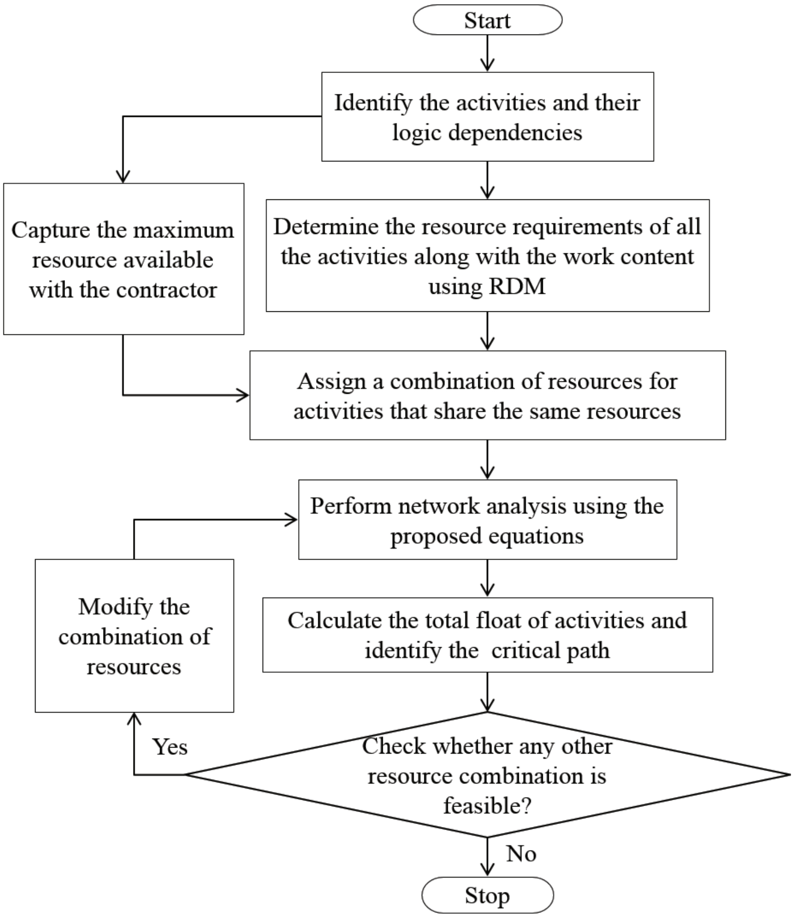

Fig. 2. Proposed Solution Methodology

$$(EF)_j = (ES)_j + \left[\frac{Q_j - \sum_{z=1}^{k-1} (R_j)_z \times \{(d_j)_z - (d_j)_{z-1}\}}{(R_j)_{\max}} \right] + d_{k-1} \tag{1}$$

where

$(EF)_j$	=	Early finish of j^{th} activity
$(ES)_j$	=	Early start of j^{th} activity
Q_j	=	Total quantum of work for the activity
R_j	=	No. of resources available for the j^{th} activity
k	=	Priority number
$(d_j)_Z$	=	Duration of the activity under consideration in the z^{th} Pass
$(R_j)_{max}$	=	Maximum resources available to the j^{th} activity
z	=	Counter
d_k	=	Remaining duration of j^{th} activity at z

3. Case example

The application of this solution methodology was investigated using data from an ongoing project involving the construction of multiple towers. Three tower constructions represented as T1, T2 & T3 and the list of activities along with their durations are represented in Table l. The logical and resource dependencies are also shown in the table.

Table 1. Project Data

S.No.	Activity	Duration (days)	Predecessor Relationship	Resource required
1	Superstructure	240	-	-
2	Brickwork –T1	90	1FS	10 Mason + 15 Helper
3	Joinery Works – T1	75	2FS	14 Carpenter + 10 Helper
4	Flooring Works – T1	90	3FS	12 Floorer + 10 Labor
5	Painting Works – T1	80	4FS	15 Painter
6	Brickwork –T2	90	2FS	10 Mason + 15 Helper
7	Joinery Works – T2	75	3FS, 6FS	14 Carpenter + 10 Helper
8	Flooring Works – T2	90	4FS, 7FS	12 Floorer + 10 Labor
9	Painting Works – T2	80	8FS, 5FS	15 Painter
10	Brickwork –T3	90	6FS	10 Mason + 15 Helper
11	Joinery Works – T3	75	7FS, 10FS	14 Carpenter + 10 Helper
12	Flooring Works – T3	90	8FS, 11FS	12 Floorer + 10 Labor
13	Painting Works – T3	75	9FS, 12FS	15 Painter
14	Miscellaneous	25	5FS, 9FS, 13FS	

3.1. Case 1

Resource availability as well as various resource combinations used in this case are given in Table 2. Network computations were done in accordance with the proposed solution methodology as found in Fig. 2. As the number of resources required are more than those required for one activity, all the activities in T1, T2 and T3 can be started simultaneously. It is randomly assumed that 10 masons are allocated for brickwork of tower T1, 3 masons for tower T2 and remaining 2 to tower T3. Network analysis for this case is presented in Table 3. It can be observed that all the activities of T3 have become part of the critical path as shown in Fig. 3 with the duration of 1051 days.

Table 2. Maximum availability of resources and resource combinations for Case 1

Resource type	Resource ID	Maximum availability/day	Combination 1 (T1, T2, T3)	Combination 2 (T2, T3)
Mason	M	15	10, 3, 2	10, 5
Carpenter	CP	15	14, 1, 0	8, 7
Tile layer	TL	15	12, 2, 1	12, 3
Painter	P	20	15, 3, 2	15, 5

Table 3. RDM network analysis for Case 1

S. No.	Activity	Resources	Early Start	Duration	Early Finish	Late Start	Late Finish	Total float
1	Superstructure	-	$(ES)_{Super} = 0$	240	$(EF)_{Super}$ =0+240=240	0	240	0
2	Brickwork –T1	Mason crew	$(ES)_{B\text{-}T1} = (EF)_{Super}$=240	$Duration_{B\text{-}T1} = [Q_{B\text{-}T1} - \sum(R_{B\text{-}T1})_z \times \{(d_{B\text{-}T1})_z-(d_{B\text{-}T1})_{z-1}\}/(R_{B\text{-}T1})_{max}]+d_{k-1}$= [(90x10-0)/10]+0 = 90	$(EF)_{B\text{-}T1} = (ES)_{B\text{-}T1} + Duration_{B\text{-}T1}$= 240+90 = 330	691	781	451
3	Brickwork –T2	Mason crew	$(ES)_{B\text{-}T2} = (EF)_{Super}$=240	$Duration_{B\text{-}T1}$= [(90x10-{3x90-0})/10]+90 = 153 (After brickwork for T1 is over, available resource for T2 is 10 as per combination 2)	$(EF)_{B\text{-}T2} = (ES)_{B\text{-}T2} + Duration_{B\text{-}T2}$= 240+153 = 393	367	520	127
4	Brickwork –T3	Mason crew	$(ES)_{B\text{-}T3} = (EF)_{Super}$=240	$Duration_{B\text{-}T3}$= [(90x10-{2x90+5x(153-90)}/15]+153 = 180 (After brickwork for T2 is over, available resource for T3 is 15 as per combination 2)	$(EF)_{B\text{-}T3} = (ES)_{B\text{-}T3} + Duration_{B\text{-}T3}$= 240+180 = 420	240	420	0
5	Joinery Works – T1	Carpenter crew	$(ES)_{J\text{-}T1} = (EF)_{B\text{-}T1}$=330	$Duration_{J\text{-}T1}$= [(75x14-0)/14]+0 = 75	$(EF)_{J\text{-}T1} = (ES)_{J\text{-}T1} + Duration_{J\text{-}T1}$330+75 = 405	781	856	451
6	Joinery Works – T2	Carpenter crew	$(ES)_{J\text{-}T2} = (EF)_{B\text{-}T2}$=393	$Duration_{J\text{-}T2}$= [(75x14-1x75)/8]+75 = 196	$(EF)_{J\text{-}T2}$ = 393+196 = 589	520	717	127
7	Joinery Works – T3	Carpenter crew	420	210	630	420	630	0
8	Flooring Works – T1	Flooring crew	405	90	495	856	946	451
9	Flooring Works – T2	Flooring crew	589	165	754	717	882	127
10	Flooring Works – T3	Flooring crew	630	216	846	630	846	0
11	Painting Works – T1	Painting crew	495	80	575	946	1026	451
12	Painting Works – T2	Painting crew	754	144	898	882	1026	127
13	Painting Works – T3	Painting crew	846	180	1026	846	1026	0
14	Miscellaneous	-	1026	25	1051	1026	1051	0

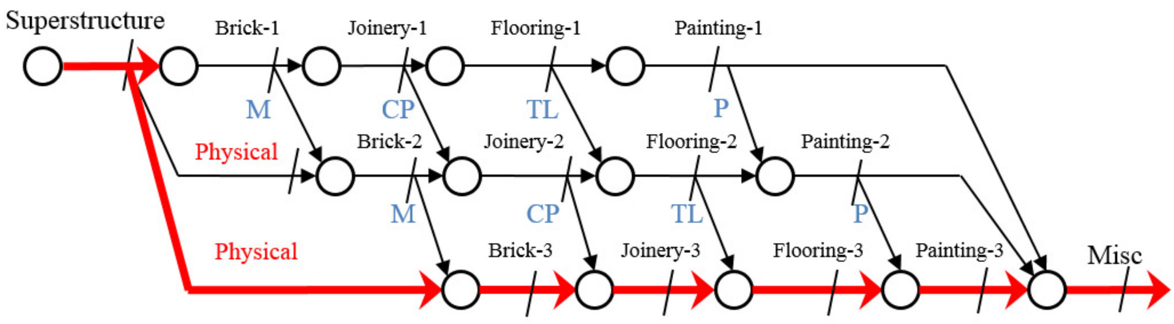

Fig. 3. RDM network showing critical path for Case 1

3.2. Case 2

Similarly, the network computations were performed for the same set of activities with a different resource combinations as given in Table 4 and the corresponding network calculations are shown in Table 5. It can be noted that the resultant critical path in this case comprises of the activities of T2 as shown in Fig. 4 with the duration of 958 days.

Table 4. Maximum availability of resources and resource combinations for Case 2

Resource type	Resource ID	Maximum availability/day	Combination 1 (T1, T2, T3)	Combination 2 (T2, T3)
Mason	M	15	6, 5, 4	8, 7
Carpenter	CP	15	5, 6, 4	7, 8
Tile layer	TL	15	3, 5, 7	9, 6
Painter	P	20	8, 6, 6	10,10

Table 5. RDM network analysis for Case 2

S. No.	Activity	Resources	Early Start	Duration	Early Finish	Late Start	Late Finish	Total float
1	Superstructure	-	0	240	240	0	240	0
2	Brickwork –T1	Mason crew	240	150	390	257	407	17
3	Brickwork –T2	Mason crew	240	168	408	240	408	0
4	Brickwork –T3	Mason crew	240	180	420	257	437	17
5	Joinery Works – T1	Carpenter crew	390	167	557	407	575	17
6	Joinery Works – T2	Carpenter crew	408	168	576.	408	576	0
7	Joinery Works – T3	Carpenter crew	420	179	599	437	617	17
8	Flooring Works – T1	Flooring crew	557	210	768	575	785	17
9	Flooring Works – T2	Flooring crew	576	197	773	576	773	0
10	Flooring Works – T3	Flooring crew	599	154	753	617	771	17
11	Painting Works – T1	Painting crew	768	148	916	785	933	17
12	Painting Works – T2	Painting crew	773	159	933	773	933	0
13	Painting Works – T3	Painting crew	753	162	916	771	933	17
14	Miscellaneous	-	933	25	958	933	958	0

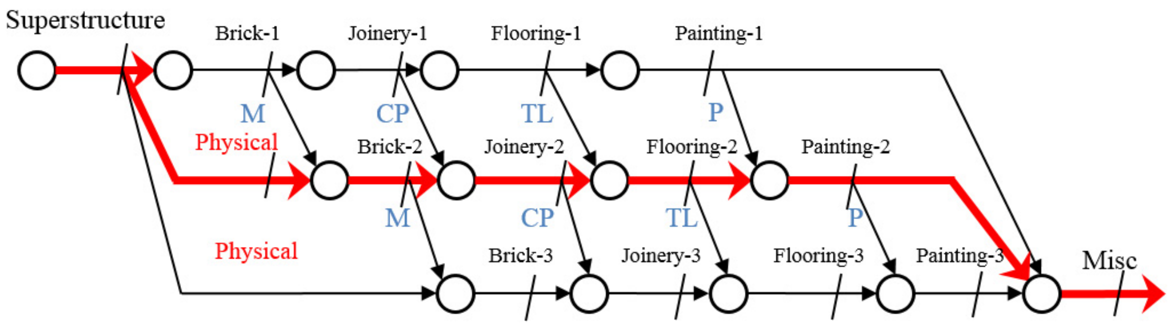

Fig. 4. RDM network showing critical path for Case 2

4. Discussions & Summary

The traditional scheduling techniques have limitations in capturing additional information in order to represent the real construction scenario. RDM network can capture the additional information in the form of several codes such as Event code, Reason/why code, Expanded lead/lag code, Duration code and Relationship code. This study has been focused on the use of Reason/Why Code in capturing the resource constraints. It has been observed that activities can be resource dependent or logical dependent and the traditional method could not distinguish between these two restraints. The purpose of reason/why code is to capture the dynamic dependency between the activities to check whether any two or more activities can execute in sequence or in parallel based on the resource availability.

What-if analysis of the proposed network analysis for the various combination of resources revealed the impact on critical path and project duration. This approach was well received by the experts as a useful tool for what-if analysis with varying resource availability. The present study is an initial attempt on the application of RDM in construction projects and there is lot of scope for improvement, which has to be done with the help of field experts and case studies.

Application of other codes of RDM can be explored to better represent the construction projects. For instance, duration of restraints dependent upon the measurement of activity progress measured by units of scope performed, estimates of remaining duration, or percent of scope complete can be represented using Duration Code [18]. This cam result in improved estimation of project duration.

Acknowledgements

The authors would like to acknowledge DST (Department of Science and Technology, Government of India, New Delhi) for providing financial support for this research work.

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